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Toward a Theory of Adaptive Training

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13. ABSTRACT (*Maximum 200 words*)

The purpose of this report is to identify conditions under which methods of adaptive training are more efficient than practicing criterion tasks. The author used examples of tasks for which adaptive methods might be helpful, derived a notional adaptive training paradigm from the examples, critiqued the paradigm in light of research results, identified variables that change the effectiveness of adaptive methods, derived testable hypotheses about the effects of each variable, and developed algorithms for deciding whether to use adaptive training and, if so, what kind and under what conditions. Variables to consider when deciding whether or not to use adaptive training and, if so, what kind include the salience of initiating or discriminative stimuli, the salience of maintaining stimuli or reinforcers, means for altering salience (augmenting and supplementing signal, attenuating, and masking noise), sensory mode, and the relative salience of practice and criterion stimuli.

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Technical Report 959

Toward a Theory of Adaptive Training

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FOREWORD

To behavioral scientists, one of the most interesting advantages of computer-based training devices is the ability of those devices to alter stimulus characteristics on command; target size, for example, or obscurity, or angle of regard. Because teaching consists of presenting and altering stimuli in ways that promote learning, researchers naturally want to know what kinds of stimulus alterations are likely to yield training efficiencies.

Adaptive training includes the use of stimulus alterations for adjusting task difficulty to match student's proficiency. Prominent behavioral scientists have dismissed adaptive training as a failed "intuitively attractive idea" because it has not proved more effective than practicing criterion tracking tasks and because it rests on "simplistic concepts such as . . . difficulty." Notwithstanding those objections, the author of this report suggests that the issue of how to systematically design training for tasks that are too difficult to master by criterion practice alone remains unresolved. The author operationalizes difficulty by reference to independent variables and presents testable predictions and usable algorithms for determining the conditions under which various methods of adaptive training can be expected to prove more and less efficient than practicing criterion tasks.

We believe instructional designers and others working to increase the efficiency of device-mediated training will find the decision algorithms in this report helpful, especially in designing instruction for tasks that cannot be mastered by criterion practice alone. We also believe that behavioral scientists will find the hypotheses about adaptive training useful in resolving the apparently contradictory results of research to date and in designing research to assess the efficiency of adaptive training. Finally, we hope that training-device engineers and buyers will see the implications of adaptive-training theory for simulator design: The benefits of adaptive training can be realized only if early planning includes device characteristics that will permit necessary stimulus alterations.

EDGAR M. JOHNSON
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TOWARD A THEORY OF ADAPTIVE TRAINING

EXECUTIVE SUMMARY

Requirement:

The requirements this work addressed were to identify the conditions under which various methods of adaptive training would be more and less efficient than practicing criterion tasks and to derive a set of assumptions, hypotheses, and principles about adaptive training that have the characteristics associated with good theory: namely, to explain existing data, predict results from experimental treatments, and generate testable hypotheses.

Procedure:

The procedure consisted of hypothesizing examples of tasks for which adaptive methods might be useful, deriving a notional adaptive training paradigm from the examples, critiquing the paradigm in light of research results, identifying variables that alter the effectiveness of adaptive methods, deriving testable hypotheses about the effects of each variable, and developing algorithms for deciding whether to use adaptive training and, if so, what kind and under what conditions.

Findings:

The findings consist of four algorithms for deciding whether to use adaptive training and, if so, what kind. Key variables in the decision algorithms are the salience of initiating or discriminative stimuli, salience of maintaining stimuli or reinforcers, means for altering salience (augmenting and supplementing signal, attenuating, and masking noise), sensory mode, and relative salience of stimuli in practice and criterion tasks. A set of testable hypotheses is presented for use in empirical examinations of the assumptions underlying the decision algorithms.

Use of Findings:

The algorithms presented in this report can be used for deciding whether adaptive training will be more efficient than criterion practice and, if so, how to choose among adaptive methods. The hypotheses provide a basis for research to examine empirically the assumptions underlying the decision algorithms and for explanations of contradictory results of adaptive-training research to date.

TOWARD A THEORY OF ADAPTIVE TRAINING

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TOWARD A THEORY OF ADAPTIVE TRAINING[1,2]

Introduction

Teaching consists of presenting and altering stimuli in ways that promote learning. When an instructor explains and demonstrates disassembly of a breechblock, for example, he is generating auditory and visual stimuli that he expects to promote learning the task at hand. As learning proceeds, the instructor alters the stimuli he presents to trainees. The alterations occur mainly in the kinds and amounts of prompting and in the kinds and amounts of feedback provided to the trainees: More feedback about correctness and incorrectness of performance and more prompting usually are given early in training than later. The teaching process is a kind of weaning, in which response control is shifted from instructor-generated stimuli to stimuli associated with criterion tasks. (When I use "criterion tasks" I am referring to the tasks to which training is expected to transfer; that is, "transfer tasks," "target tasks," "Tasks B," even if they are not the tasks that constitute the ultimate criterion.)

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[1]This is a slightly edited version of an unpublished manuscript I drafted in 1979 while I was with the Human Resources Research Organization doing tank-gunnery training research under contract DAHC 17-76-C-0001 with the U.S. Army Research Institute. I believed then as I do now that the effects of adaptive training could be explained by analyses of discriminative stimuli and reinforcers in practice and criterion tasks and by reference to research done by experimental psychologists mainly before 1960. In following adaptive training developments over the years, I read Adams's 1987 review in which he dismissed adaptive training as a failed "intuitively attractive idea" (p. 52) because it had not proved more effective than practicing criterion tracking tasks. That triggered old thoughts about how to teach tasks that are impossible to master by criterion practice alone. I also read Lintern, Roscoe, and Sivier's (1990) article, in which they dismissed (after Holding, 1962) "simplistic concepts such as . . . difficulty. . . ." (p. 315). That triggered old thoughts about the need to operationalize difficulty (a dependent variable, as Adams noted) by reference to independent variables. More precise definitions of variables and operations than have been offered earlier are, I believe, necessary if we are to understand the conditions under which adaptive training will be more efficient than criterion practice.

[2]I am grateful for the thoughtful reviews provided by James W. Altman, David W. Bessemer, Ronald G. Hughes, Edgar M. Johnson, John E. Morrison, and Paul J. Tremont. I especially thank William C. Osborn for his reviews and for his perseverance in urging me to publish.

Teaching machines share with instructors the characteristic of being stimulus-presenting systems. Of the many advantages of teaching machines, one of the most compelling is the precision they offer in controlling stimulus materials for presentation to learners - control precision, not only in the kinds of stimuli presented, but also in presentation rates: Teaching machines typically present stimuli at a rate governed by the learner's response rate. The advantage in doing so is in requiring the learner to make a response (i.e., practice) before proceeding from one frame to the next.

Computer-based training devices and simulators offer all the advantages of conventional teaching machines and other potential benefits as well. Of the other potential benefits, one of the most interesting is the ability of computer-based devices to alter stimulus characteristics on command - target size, for example, or obscurity, or angle of regard - in ways that would be difficult without computers.

Rationale

The U.S. Army is in the process of contracting for the design and purchase of many electronic training devices and simulators. Given the flexibility in design and function offered by electronics, a question naturally arises as to whether the forthcoming devices should incorporate the capability to alter stimulus characteristics as discussed above. That question can be answered in light of answers to other questions; namely:

1. Can the capability to alter stimulus characteristics be used to promote learning?

2. What kinds of alterations are possible?

3. Given the possible alterations, what variables influence the effectiveness of each?

4. Under what conditions will learning be better promoted by altering stimuli than by not doing so?

The answer to the first question above is affirmative, both on an intuitive basis and in light of certain evidence. Much of the psychology of learning is aimed at identifying the extent to which various arrangements and characteristics of stimuli promote learning. That some stimulus characteristics and configurations promote learning better than others is self-evident.

One method of systematically altering stimulus characteristics as a means to promote learning has come to be known as "adaptive training." Machine-controlled adaptive training is, as Kelley (1969) noted,

"merely the automation of a function performed by a skilled instructor. . . . [It] automatically gets harder as the subject becomes more skilled" (pp. 547-548).

The results are mixed. Adaptive training seems more efficient than non-adaptive methods mainly in clinical situations (e.g., Goldiamond, 1965), about equally efficient in other cases (Kelley, 1969), and less efficient in still others (Hughes, Paulsen, Brooks, and Jones; 1978).

Purpose

The purpose of writing this paper was to identify the conditions under which adaptive training can be expected to be more and less efficient than non-adaptive methods; less modestly, my purpose was to develop a set of assumptions, hypotheses, and principles that have the characteristics we customarily associate with good theory; namely:

1. Explains existing data.

2. Predicts results from experimental treatments.

3. Generates testable hypotheses.

Method

I developed the rudiments of a theory of adaptive training by:

1. Considering some hypothetical examples in which adaptive methods might seem to promote learning faster than non-adaptive methods.

2. Inducing from the hypothetical examples, a notional or straw-man adaptive training paradigm.

3. Raising questions about the adaptive training paradigm and answering them by reference to published research.

4. Examining some studies in which adaptive methods have and have not promoted learning faster than criterion practice.

5. Comparing research results with the notional paradigm, for the purpose of identifying strengths and weaknesses.

6. Evolving a summary of hypotheses that explains and predicts results in ways that are testable and lead to development of algorithms about the conditions under which various adaptive methods should and should not be used.

Hypothetical Examples

Adaptive techniques can be understood by considering how they might be used and perhaps misused in teaching armor crewmen to take a correct sight picture before firing and to adjust fire after a miss.

Taking a Correct Sight Picture

Taking a correct sight picture before firing may not be learned efficiently using tanks because sight pictures and hit probabilities are not perfectly related. Fingerman (1978), for example, reported that with perfect sight pictures we can expect to hit the target using the 105 mm gun of M60 series tanks about eight times in ten. Undesired effects (e.g., superstitious behavior) on learning to take a correct sight picture before firing might be reduced as follows: Early in training, we might award a hit every time a simulated main gun was fired when the sight picture was correct. We also might make the target's apparent size greater than it would be in situ, credit hits for slightly incorrect sight pictures, or both. Training would then proceed through exercises in which the target would be made smaller, the sight picture would have to be better, and the probability of getting a hit with a correct sight picture was decreased. Finally target size might be decreased to criterion levels and for every ten correct sight pictures trainees would get eight hits. The objective in stretching the contingency from 100% to 80% is, of course, to teach persistence in the face of imperfect equipment. A case might even be made for stretching the contingency further - say seven or six hits for every ten correct sight pictures - than will be the case in the real world, as a means of producing overlearning of persistence and high rates of firing.

Adjusting Fire

Learning to adjust fire after a miss with 105 mm rounds is sometimes difficult. The rounds' high velocities and possible target obscurity due to smoke and dust can make it difficult to see where a miss went. A training device might facilitate learning by presenting slow rounds with prominent tracers and little or no target obscurity early in training - not very realistic, but better from a teaching standpoint than letting trainees lose the results of their early efforts in a cloud of dust. As training proceeded and trainees mastered firing slow rounds with tracers and little or no obscurity, the velocity might be systematically increased, tracers systematically faded, and obscurity systematically increased. Still later in training, velocities and obscurity would simulate live-firing conditions realistically.

An Adaptive Training Paradigm

The main thing that was manipulated in the two examples cited above was the salience or noticeability of the stimuli that initiate task performance and of the stimuli (feedback) that maintain task performance. One underlying assumption was that learning difficult tasks will be facilitated if early in training we increase the salience of stimuli that initiate task performance and increase the potential reinforcing value of stimuli that maintain performance.

Another assumption underlying the hypothetical examples was that after training under initial conditions of increased stimulus salience, learning will be facilitated if we systematically diminish the salience of initiating and maintaining stimuli until criterion levels are duplicated or surpassed – a procedure, when applied to prompts in programmed instruction, known as "fading."

Inspection of the examples indicates that salience was varied in a number of ways, which can be described in the context of an adaptive training paradigm:

1. In the early stages of training, increase the salience of initiating stimuli by increasing the signal-to-noise ratio (S/N).

1.1. Salience may increased by increasing S strength, decreasing N, or both.

1.1.1. Signal strength may be increased by augmenting or supplementing.

1.1.1.1. Augmenting means increasing the value of a dimension of S – its size, for example, or brightness, or frequency of appearance, or probability of occurrence.

1.1.1.2. Supplementing means adding a new dimension to S; a flashing light indicating that a tank's main gun safety switch is in the firing position is an example, as is the addition of a pop-up feature to tank targets.

1.1.2. Noise may be decreased by attenuating or masking.

1.1.2.1. Attenuating means decreasing the value of a dimension of N – its size, brightness, frequency of appearance, or probability of occurrence, for example. Attenuating is the opposite of augmenting, applied to N.

1.1.2.2. Masking means adding a new dimension to the N. Tones introduced into the ears of people with tinnitus for the purpose of cancelling ringing exemplify masking. (Masking will not be considered

in the analyses that follow. It seems not to have been used in adaptive training, probably because it is difficult to implement and because its advantages over attenuating are not apparent. Masking might be useful for teaching abient behavior where [a] adient dispositions are strong and [b] attenuating is not feasible. I cannot think of an example.)

2. Also in the early stages of training, increase the potential reinforcing value of maintaining stimuli by increasing their salience by augmenting S, supplementing S, or attenuating N.

3. Later in training, diminish the salience of initiating stimuli by systematically decreasing S/N until criterion levels are reached or surpassed.

4. Also later in training, decrease the salience of maintaining stimuli by systematically decreasing S/N until criterion levels are reached or surpassed. This includes contingency-stretching, in which the immediacy of maintaining stimuli, their probability of occurrence, or both are reduced from the artificial levels used in training to criterion levels.

Notice that all manipulations in the salience of initiating and maintaining stimuli constitute reducing "fidelity" as means for increasing training efficiency.

Assumptions

Inspection of the examples and of the paradigm reveals several assumptions made in their development.

One assumption was that salience-altering techniques will be more efficient than practicing criterion behavior only with tasks that are difficult to learn. I chose the examples because I assumed they were difficult tasks. If they are not, then altering salience as suggested in the paradigm will be of no value. If a task is easy enough to master in a few trials or on the basis of simple instructions, then adaptive techniques or any other aspects of modern instructional technology have nothing to offer. Selecting tasks for laboratory study on the basis of manageability may stack the cards against the adaptive techniques. The payoffs from adaptive techniques will be greatest where we can identify elements of a task or tasks of a job that are (a) critical to effective performance and (b) difficult to master.

Early applications of what are now called adaptive techniques were in clinical settings. Desensitization for the treatment of phobias (Wolpe, 1954, 1958) and the behavior-modification techniques of Goldiamond (1965) systematically alter the salience of initiating and maintaining stimuli as means for eliciting desired behavior - behavior

that is so difficult to learn that it might be impossible to master without the adaptive techniques. "Difficulty" as I am using it is an individual characteristic: Standing on high bridges is difficult for acrophobics, but not for others. Extending the concept of difficulty as an individual characteristic to mental ability suggests a corollary to the first assumption; namely, given an objective that is easily mastered by persons with high mental ability and mastered only with difficulty by persons with low mental ability, salience-altering techniques will be more effective for the low- than for the high-ability persons. Similar corollaries apply to masters and non-masters, stages of learning, and amount of experience.

A second assumption, related to the first, is that adaptive (salience-altering) techniques will be effective only with tasks that are difficult to learn because the salience of initiating stimuli, maintaining stimuli, or both, is low. Indirect support for this assumption is provided in the work of Hughes (1978), who mapped the domain of instructional features: Examples included preflight briefings, flight demonstrations, freeze and preprogrammed initial condition sets, augmenting physical cues, performance records and replay, and control of task tempo. The characteristic shared by instructional features is that each increases the salience of the stimuli that initiate or maintain task performance or some aspect of task performance. The same is true for part-task training.

If the stimuli that initiate and maintain the behavior are discriminable 100% of the time, then augmenting or supplementing those stimuli will not facilitate learning. Doing so may in fact disrupt transfer by allowing learners to respond to stimuli that are different from those that initiate and maintain criterion performance and may produce a crutch effect (discussed later) when transferring from the practice environment to the criterion environment.

The effectiveness of salience-altering techniques only with behavior that is difficult to master because of low salience presents problems for theory development. My initial inclination was to suggest that the only reason tasks can be difficult to learn is because at some level - task, subtask, overt-response, mediating-process - the salience of initiating or maintaining stimuli is low. That is, all motor responses that could conceivably be involved in the performance of military or industrial job tasks are already in the repertoires of trainees. Adult humans hardly ever learn motor responses; we learn rather to recognize conditions under which motor responses in our repertoires are and are not to be made. My speculations here must be tempered with consideration of tasks whose essence of performance is speed: Tasks such as those performed by professional athletes are conceivable in which initiating stimuli and maintaining stimuli are perfectly discriminable, but which learners simply cannot perform fast enough. The upper limits on performance of such tasks are given by nature. Below the upper

limits no compelling hypotheses about the efficacy of altering salience come to mind. On the one hand, building speed by practicing running slowly makes little sense. On the other hand, teachers of skills such as typing and piano playing sometimes admonish students to "build speed" by practicing slowly. In typing and piano playing, however, unlike in running, new accuracy components are being learned in addition to speed. The slow practice may simply represent an attempt to automatize accuracy before practicing speed. Exactly what is learned in the slow practice of typing and piano playing is unclear. Slow practice may, however, be the only feasible method of augmenting the cutaneous and kinesthetic stimuli that initiate and maintain the behavior.

As implied earlier, the measure of effectiveness for salience-altering techniques is how they compare, in terms of time or trials to mastery, to practicing the criterion. By definition then, another assumption: Salience-altering techniques will yield high rates of learning. The extent to which high rates of learning conflict with or complement retention is unclear (anecdotal evidence on cramming, for example, notwithstanding), probably because retention is subject to influences far more potent than acquisition rate. If a rule of thumb is required, aim for high rates of acquisition. Once mastery is achieved, deal with retention as a separate problem. (See Krueger [1929] for example, on the relation between overlearning and retention.) Study, if need be, the relation ad hoc, with particular attention to controlling or randomizing what subjects learn between the first demonstration of mastery and the first retention trial.

Chief assumptions in developing the examples and the paradigm involved, obviously, the relation between salience and learning. Those assumptions are by no means unequivocal. Before examining each, I shall define in more detail than before the concepts of initiating stimuli, maintaining stimuli, and salience. Initiating stimuli are Skinner's (1957) discriminative stimuli, E.J. Gibson's (1969) perceptual invariants, the "cues" of aviation psychologists. They set the occasion for a response, increase its probability, and their absence makes a given response unlikely. Not all stimuli that precede a response are initiating. Whether a stimulus is initiating (discriminative) is given by the difference between the effects of its presence and absence upon response probability. A sight picture is an initiating stimulus for firing rifles. Without it, a correct response is unlikely; with it, a correct response is possible. Initiating stimuli serve to limit the kinds and numbers of responses available to learners, to focus attention, to create a set.

Maintaining stimuli occur as the result of responding. They are the reinforcers of behavioral science. Not all stimuli that follow a response are maintaining. Whether a stimulus is maintaining is given by the difference between the effects of its presence and absence on response probability. The distinction made by Gagne (1954) and by

Annett and Kay (1957) regarding feedback applies: Some response-produced stimuli provide information that learners can use to improve their performance; others do not. Those that do are maintaining stimuli.

A given response may have various initiating and maintaining stimuli and given stimuli can initiate and maintain various responses. The effects of given initiating stimuli and maintaining stimuli may vary within an organism, among equally mature organisms, as functions of maturity with species, and depending upon proficiency or stage of learning.

Salience, as noted earlier, refers to the noticeability or discriminability of stimuli. Salience is thus a property, not of stimuli, but of organisms' responses to stimuli. The methods and metrics appropriate for measuring salience are those used in psychophysics for establishing sensitivity (absolute threshold) and acuity (difference threshold). Salience may be altered by altering either the primary or secondary qualities (Galilei, cited in Danto and Morgenbesser, 1961) of stimuli; size and shape, for example, or wavelength, intensity, duration, and frequency. Salience is not, however, linearly related to values of physical properties of stimuli, as evidenced by such phenomena as equal-pitch contours, equal-loudness contours, equal-brightness contours, the Fletcher-Munson effect, the Ramon Shift, the Purkinje Phenomenon, and so forth.

My central assumption about salience and learning is that many, if not all, tasks are difficult to learn because the stimuli that initiate or maintain the performance are not reliably discriminable from other stimuli. (But see earlier and later comments about performance speed.) We may, for some clues about the tenability of that assumption, examine the extremes of hypothetical relations between response probability and the salience of initiating stimuli and maintaining stimuli. Initiating stimuli first: At the low end of the salience/response-probability curve, it seems that if initiating stimuli are not noticed then the response is unlikely to be emitted – a probability of zero for practical purposes. At the high end of the salience/response-probability curve, the relation is less clear: Once initiating stimuli are noticeable 100 percent of the time, neither necessity nor sufficiency is fully served. Learning undoubtedly can occur with less than 100% salience. And even with 100% salience, learning is not guaranteed. Response probability seems, however, to increase – albeit at an unknown rate – between zero and 100% salience, all other things (the salience of maintaining stimuli, for example) being equal. Corollaries of the difficulty assumption then, are: (a) As salience of initiating stimuli increases from zero to 100 percent, response probability increases, all other things being equal; and (b) the average slope of the salience/response-probability curve is less than one. (The relation is not totally reliable.)

The relation between salience and response probability can be examined for maintaining stimuli as it was for initiating stimuli. At the low end of the salience/response-probability curve, a given response is unlikely if the maintaining stimuli are unnoticed. Data on incidental learning provide an apparent, but perhaps unimportant, contradiction. Treatises on "Can learning occur in the absence of reinforcement?" or "Can learning occur in the absence of discriminable maintaining stimuli?" seem ultimately fatuous inasmuch as the questions can only be answered if all possible reinforcers are identified. If learning occurs in the apparent absence of reinforcement, the aberration can be explained in at least two ways; namely, that reinforcement is unnecessary for learning or that the experimenters lacked sufficient observational powers and methods to identify reinforcers that were in fact operating. The data on performance feedback in any event seem to favor that learning is more likely to occur in the presence of discriminable maintaining stimuli than in their absence.

At the high end of the function, my speculations about response probability and the salience of maintaining stimuli are as they were for initiating stimuli: Learning does occur under contingencies of less than 100% reinforcement, and depending on many variables - stage of learning, for example, or whether high response rates or low are being reinforced - can be faster under less than 100% reinforcement. Generalities are nevertheless needed if we are to predict the effects of altering the salience of maintaining stimuli. Assumptions are as they were for initiating stimuli: (a) As salience of maintaining stimuli increases from zero to 100%, response probability increases, all other things being equal (the salience of initiating stimuli, for example); and (b) the average slope of the curve is less than one.

The adaptive training paradigm, in addition to resting on the assumptions discussed above, leads to specific questions about its application. The questions are:

1. How do we decide whether to alter initiating stimuli, maintaining stimuli, or both?

2. How do we choose among augmenting, supplementing, and attenuating?

3. Under what conditions should we use fading?

Alter Initiating Stimuli, Maintaining Stimuli, or Both?

The hypothetical examples showed salience being increased in early training and decreased later for both initiating and maintaining stimuli. The obvious question is, "Is it necessary to operate on both in all cases?" The equally obvious - from the preceding discussion of

difficulty - answer is, "No." Whether the salience of initiating stimuli, maintaining stimuli, or both should be altered depends on answering the question, "Why is the task difficult to learn?" The only permissible answers according to my scheme are, "Because of low salience of initiating stimuli," "Because of low salience of maintaining stimuli," or both. Selecting an answer is undoubtedly an art form, but seems easy, at least for the two hypothetical examples discussed earlier. It involved deciding whether the task was difficult because the learner might not recognize the conditions under which a response was to be made or because the learner might not distinguish between the results of desired responses and the results of other responses.

Augment, Supplement, or Attenuate?

Once we decide about whether to operate on the initiating stimuli, maintaining stimuli, or both, a question immediately arises as to whether to augment S, supplement S, or attenuate N. The answer to this question lies in comparing characteristics of the practice task and the criterion task. Because altered salience is a temporary condition to be replaced eventually by criterion salience, a rule of thumb suggests itself: Make the choice so that it yields the least difference between characteristics (not values of characteristics) of criterion stimuli and of the stimuli used in practice. If the choice among augmenting, supplementing, and attenuating is to minimize differences between criterion and practice stimuli, then supplementing should in nearly all cases be chosen last, because supplemented stimuli are not to be found in criterion tasks. As we shall see later, however, there are cases for which neither attenuating nor augmenting is feasible and for which supplementing has been effective.

Assuming that supplementing is normally to be chosen last, the choice for increasing salience will usually be between augmenting S or attenuating N. I can see no unequivocal guideline for making this choice for cases where both S strength and N strength are likely to vary *in situ*; that is, where increased salience may be effected by increasing S or decreasing N. Tank targets, for example, are likely to vary along several dimensions *in situ* - size, brightness, shape, and so forth. But the noise (obscurity) associated with target salience also is likely to vary *in situ* depending, for example, on the proximity of a round's impact to the target and the wetness of the impact area. Whether S strength is increased or N strength is decreased in training for such cases may not matter, because salience increases in either event. One can, however, imagine tasks in which the stimulus field is clearly too complex to allow efficient separation of S from N by novices. Attenuating N would seem preferable to augmenting S in such cases, but I could find no research bearing on the issue. If a choice between augmenting and attenuating can be made on the basis of fewest differences between characteristics of practice and criterion stimuli, that should probably be done.

Use Fading?

The hypothetical examples and the notional paradigm presented earlier incorporated fading; that is, systematically reducing the salience of stimuli used in practice until criterion salience levels are reached or surpassed: The learner practices the task under conditions of high salience until mastery of the practice task is achieved. Salience is then reduced slightly and once again the learner practices until mastery is achieved. The salience-reduction, practice, and mastery cycle is repeated until the learner is practicing with salience levels that are equal to or lower than criterion levels. Two questions about fading arise:

1. Does fading offer advantages over a more direct method in which subjects would initially practice under a single high-salience condition, then immediately begin practicing under the criterion-salience condition, omitting practice at intermediate salience levels?

2. If fading is used, what size steps should be used in reducing salience? (And the related question, "How do we select the initial high salience level to be used for practice?") No unequivocal answers to these questions present themselves. But examining some studies provides clues.

One reason for using fading is to minimize the opportunity for incorrect responding. This is important in clinical situations such as those mentioned earlier, in which we try to extinguish unwanted behavior by non-reinforcement and by practicing incompatible responses. Much of what is learned in clinical environments is, unfortunately, learned in response to stimuli that are unique to, and absent outside, those environments. On leaving the clinic, clients find that Jost's Law is alive and well: The undesired (earlier-learned) responses reappear in the face of stimuli to which they originally were conditioned.

A related reason for using fading is to avoid crutch effects,[3] in which withdrawal of a supplement produces a temporary depression in performance relative to controls who practiced without the supplement.

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[3]Bilodeau [1952b] seems to have spawned the notion of crutch effects: "Performance during training can usually be improved through effective presentation of 'knowledge of results,' for example, through informing the learner regarding the correctness of the way he is operating the trainer. In some situations, however, such information may be used as a crutch and may result in reducing the trainer's effectiveness in preparing the learner for the operational situation, where immediate 'knowledge of results' information may not be available" [p. iii].

A study by Hughes, Paulsen, Brooks, and Jones (1978) provides a case in point: An experimental group used conventional sights supplemented by a beam of light that predicted the impact of rounds in an air-to-surface weapons-delivery task. Withdrawal of the light beam after Ss had practiced using it for several trials temporarily degraded Ss' performance on subsequent trials, relative both to their own pre-withdrawal levels, and to the performance of controls who practiced from the outset using the conventional sights unsupplemented by the predictor beam. Hughes et al. suggested (p. 100) that, had the beam been gradually faded, the decrease in accuracy might not have occurred. What was done in this study was to supplement initiating stimuli that were sufficiently salient in and of themselves to permit mastery of the task, as evidenced by the control group's learning. Supplementing a salient initiating stimulus set the stage for operation of the crutch effect. The experimenters then suggested fading as a means for avoiding or diminishing the effect. My guess is that not introducing the supplement in the first place would be more efficient than introducing and fading it.

The crucial test of the efficacy of fading would be one that used a task whose initiating or maintaining stimuli were of such low salience that the task could not be mastered by criterion practice alone. Experimental and control Ss would practice to mastery under identical conditions of increased salience. Experimental Ss would then practice under conditions of progressively decreasing salience, while control Ss began practicing immediately under criterion-salience conditions. Mastery rates - final levels of achievement divided by trials or time - would be used to compare the performance of the two groups. I could find no such experiment. Examining the procedures used by Goldiamond (1977) in treating stuttering is, however, instructive.

Goldiamond's subjects used an apparatus comprising headphones and a tape recorder, which delayed auditory feedback of Ss' speech by 250 ms. Subjects quickly learned to prolong syllables and speak slowly at a rate that matched the auditory delay. (Doing so is incompatible with stuttering.) After Ss mastered prolonged speech with 250 ms delay, the delay was decreased to 200 ms and practice resumed. The procedure continued with the delay reduced by 50 ms decrements, until criterion (0 ms) delay was reached. The part of the procedure that seems especially relevant for the present discussion is that, if S began stuttering at any stage of practice, the delay was increased by 50 ms to the last level at which no stuttering occurred. That the method incorporated the provision for increasing the delay suggests that fading is important. The implication is that stuttering is less likely with greater delays that with smaller delays. It seems safe to infer then that stuttering is less likely with than without small reductions in delay. Thus, at least for this unrepresentative case, fading is more effective than not. (The case is unrepresentative of military and industrial tasks because it involves extinguishing responses that

compete with desired ones and uses aversive control to suppress the competing responses.)

The study by Hughes et al. (1978) and the procedures of Goldiamond (1977) permit no unequivocal conclusions. They do, however, suggest two appealing hypotheses:

1. If a salient supplement is added to a salient criterion stimulus and withdrawn abruptly, a crutch effect is likely to occur.

2. If a low-salience criterion stimulus is augmented, then the crutch effect is less likely to occur with than without fading. Fading thus seems important, at least at the extremes of criterion salience. An additional point is that the capability to do reverse fading - that is, to increase salience immediately after a performance breakdown, to the last level at which mastery was demonstrated - is important, not only to minimize opportunities for practicing errors, but also because the alternatives, which are continuing to practice with the salience level at which failure occurred or decreasing salience further, do not seem reasonable.

The second question about fading was about the size of the steps to use for decreasing and increasing salience. As suggested earlier, and by the Hughes et al. (1978) study, increasing the values of stimulus characteristics beyond the point where the stimulus is reliably discriminable will yield no additional benefits for learning; and, at least for supplementing, if not augmenting, will guarantee crutch effects. The guideline that emerges for how much to increase the salience of stimuli that are not reliably discriminable is to increase salience to 100%. Increasing values of stimulus characteristics additionally by augmenting cannot increase salience beyond 100%, but may not be detrimental to learning. Adding a supplement, however, will produce crutch effects. Deciding on the size of steps to be used for decreasing salience reduces then to a question of how to divide the difference between criterion and 100% salience. The decrements probably should occur in steps slightly smaller than 1 j.n.d., so S will not notice the change and, one hopes, will continue to make desired responses. Exact decrements in stimulus values equivalent to slightly less than 1 j.n.d. could be identified empirically, but only at considerable expense. A more straightforward approach would be to set an arbitrary mastery cutoff at, say, 85% and run Ss at 100% salience until that mastery level is reliably achieved. Then reduce the value of the manipulated stimulus characteristic by various amounts, identify the fractional reduction in value at which 85 percent mastery is once again reliably achieved, and repeat the procedure until the cutoff mastery level is achieved under criterion salience.

Apparent Contradictions

Two sets of studies warrant examination because they seem to contradict key aspects of my notional paradigm. In the first set of studies, increases in target size had no effect on acquisition. In the second set, supplementing - the last in my recommended order of means for increasing salience - facilitated learning.

Target Size May Not Affect Acquisition

Bilodeau (1952a) found no difference in the accuracy of lever-positioning performance as a function of target size: The apparatus comprised two parallel 44-light columns - one red and one green. Pulling a lever would "move" the light up the column of green lamps. Subjects were told to pull the lever just enough to match targets given by the red lights. The targets were, for one group of Ss, a single red light; and for a second group, three contiguous red lights. For these two groups a delay of 5 sec was introduced between the end of the lever-pulling response and the green lamp's lighting. A third group was designated Faked Wide Target. Like the second of the first two groups, they were shown a target consisting of three contiguous red lights. The Faked Wide group, however, could only achieve a match by adjusting the lever so that the position of the green lamp matched the position of the red lamp in the center of the three-lamp target. Because Faked Wide Ss were not told this, they probably believed that a match could be effected by positioning the green lamp to coincide with a position of any of the three red target lamps. In addition, a constant error was introduced so that when the uppermost of the three target lamps was matched by a Faked Wide S, the green lamp in the next higher position lighted; and when the lowermost of the three red lamps was matched, the green lamp in the next lower position lighted. A match with the center red lamp lighted the corresponding green lamp. Bilodeau did not report the response-feedback interval for the Faked Wide group, but wrote that the procedure outlined above, "assured fewer hits and/or larger reported errors (at least during the early trials) than for the other two groups" (p. 2).

Each of the three groups received ten practice trials under one of the three treatments, followed immediately by eight test trials with the center light as the target.

Differences among means were found as a function neither of treatment nor of practice. The standard deviations did, however, show a declining trend, most dramatically during the first three practice trials. Bilodeau reported, "These results are in agreement with those of Gagne [1950] and Bilodeau [1952b] where target sizes have been manipulated by using somewhat different treatments and/or apparatus"

(p. 4). In a section of the article entitled, "Implications for the Air Force," Bilodeau wrote,

> In training men on skills requiring considerable accuracy it has frequently been considered desirable during early stages of practice to provide for relatively large accuracy tolerances, and to encourage the learner by making possible relatively frequent "success" in meeting the accuracy demands of the task. Previous research has suggested that, at least in some activities, this rather widely held belief may not be justified, in that men originally trained with generous tolerances in general do no worse, or no better, on the final task than do men initially trained to the same tolerances required by the final task (p. iii).

Bilodeau's results and the results of others cited by Bilodeau seem to contradict parts of my hypothetical examples, especially those parts in which I suggested increasing target size in early training to promote learning to adjust fire. Notice, however, that the initiating and the maintaining stimuli used by Bilodeau were salient (although wonders what would have happened had the response-feedback interval been decreased or increased). The criterion task was not difficult to learn, as evidenced by rapid improvement of all groups over the first three trials. Perhaps more important, in many aiming tasks, tracking tasks, and matching tasks, the aiming point is not necessarily given by target size. For any but very small or very large targets, Ss are free to set their own standards for accuracy: They can aim anywhere they choose within the area the experimenter calls "target." One would (unless being scored for speed), I suspect, tend to aim at target centers unless told to do otherwise, creating in effect one's own target within the experimenter's target. In cases where doing so were not possible - that is, where target centers were indiscriminable from other parts of the target, as with very large or very small targets - adaptive techniques might work. Bilodeau considered that possibility: "Though a number of situations have been reported in which target size is an irrelevant variable, it remains conceivable that use of very large or small targets may lead to results different from manipulation of intermediate sizes" (p. 4).

Thus the results of the target-size studies, while seeming to contradict some points made earlier, are consistent with others; namely, that adaptive techniques will be:

1. More efficient than practicing the criterion only with tasks that are difficult to learn.

2. More efficient than criterion practice only with tasks that are difficult to learn because the salience of initiating stimuli, maintaining stimuli, or both is low. And the corollary: If the stimuli that initiate and maintain the behavior are discriminable 100% of the time, then augmenting or supplementing those stimuli will not facilitate learning.

Supplementing May Be Effective

Two studies, in which cutaneous and kinesthetic maintaining stimuli were supplemented with visual stimuli, are interesting. English (1942, cited in Wolfle, 1951) reported a study performed in 1918, in which naive Ss were taught trigger-squeezing by allowing them to compare visual representations of their own squeezes to visual representations of experts' squeezes. The visual representations were provided by a kymograph and the movement of liquid in a glass tube, both actuated by a syringe-like bulb in the stock of a rifle. Use of the visual supplements produced satisfactory learning in Ss who had previously failed to master the task without the visual supplements.

The second study was by Lindahl (1945, cited in Wolfle, 1951). The task was cutting discs from a tungsten rod, using a treadle-operated slicing machine. Improper patterns of foot pressure on the treadle produced "damage to the discs, excessive breakage and use of [cutting] wheels, and wastage of material" (pp. 420-421). Paper tape records of incumbent machine operators' foot movements were made and compared to the incumbents' work records. A record of ideal foot movement was thus selected for use a standard. New workers were then trained by allowing them to compare records of their own foot movements to the standard. New workers with 11 weeks of training with the visual supplement performed as well as conventionally treated incumbents with 5 months' experience.

The two studies cited above are interesting as much for their heuristic value as for their results. The chief point of interest is that supplementing, rather than augmenting or attenuating, was used in both studies. This seems contradictory, not only to what I said earlier about priorities for selecting among supplementing, augmenting, and attenuating, but also to the results of the study by Hughes et al. (1977) in which the use of a supplement produced a crutch effect, which disrupted performance.

One difference between the study by Hughes et al. on the one hand and those of English and Lindahl on the other is that the initiating stimuli were supplemented in the former and the maintaining stimuli were supplemented in the latter. The hypothesis that the crutch effect operates selectively on initiating stimuli is, however, not supported by

Lintern and Roscoe's (1978) review[4] in which augmented feedback disrupted transfer, crutch-effect fashion.

A second difference between the study of Hughes et al. on the one hand and those of English and of Lindahl on the other is in the sensory mode mediating the criterion stimuli: vision in the former and touch and kinesthesis in each of the latter. Could it be that supplementing is differentially effective depending upon sensory mode? Or that supplemented visual stimuli are more likely to produce crutch effects than are supplemented cutaneous or kinesthetic stimuli? Based only on the studies discussed here, the answer to both questions would be, "Yes." Three studies do not constitute an adequate sample for drawing conclusions, however. And the notion that supplementing - or augmenting S, or attenuating N, or for that matter, any stimulus manipulation - operates differentially depending upon sensory mode lacks intuitive appeal. The experiments cited above differed in respects other than the receiving sensory mode. One such difference was in the salience of the criterion stimuli. In the study by Hughes et al. the salience of the initiating stimuli was sufficient to produce learning without supplementing, as evidenced by the performance of the control group, which used the gunsight without the predictor beam. Thus the supplement was redundant to "intrinsic cues" (Lintern and Roscoe, 1978, p. 139). The supplemental cue also was probably more salient than were the criterion initiating stimuli. Those two conditions, a criterion stimulus of sufficient salience to allow learning and a supplementary stimulus of greater salience than the criterion stimulus, coupled with abrupt withdrawal as opposed to systematic fading of the supplementary stimulus, are sufficient for producing the crutch effect.

Further on differences between the work of English and Lindahl, and of Hughes: The tasks used by English and by Lindahl, in contrast to the one used by Hughes et al., had no intrinsic maintaining stimuli, as suggested by the failure of trigger-squeezers to learn without the supplement in one instance, and by the poor performance of incumbent disc-cutters in the other. Performance of the criterion tasks would,

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[4]Lintern and Roscoe did not explicitly distinguish between supplementing and augmenting. The contexts in which they used the terms, however, suggested that any feedback whose salience was increased by experimenters' intervention was considered "augmented," and <u>cues</u> that were added by intervention were considered "supplementary." The possibilities of supplementing feedback and augmenting cues were not addressed. It would be interesting to inspect, case-by-case, the studies reviewed by Lintern and Roscoe, to ascertain whether initiating stimuli as well as maintaining stimuli were supplemented and whether any differential effects could be ascribed to supplementing and augmenting.

in both cases, yield results - holes in targets and cut discs - that performers could inspect for information about the adequacy of their performance. Inspection of the results would, however, yield no information that could be used to make appropriate adjustments in responses on subsequent trials. The targets and discs did not by definition therefore provide maintaining stimuli. Rather, the maintaining stimuli were cutaneous and kinesthetic in both cases, and for novices, indistinguishable from irrelevant stimuli. The treatments used by English and by Lindahl facilitated learning the discrimination. If maintaining stimuli are indistinguishable from irrelevant stimuli, then anything that facilitates learning the discrimination will improve performance of the criterion task.

When dealing with responses whose initiating or maintaining stimuli are (a) kinesthetic and (b) indistinguishable from irrelevant stimuli, supplementing should receive primary consideration for increasing salience in training. Attenuating N might be effective if identifying irrelevant stimuli a priori and devising mechanisms for their attenuation were feasible. The mechanisms for doing so, however, are hard to imagine. Augmenting S also might work, but like attenuating, presents practical problems. Augmenting kinesthetic stimuli - stimuli that provide information about body orientation and limb position - would require altering criterion responses, with attendant possibilities for undesired transfer effects. Slow practice was discussed earlier. In cases where it is effective, the effectiveness probably can be explained by the infeasibility of alternatives: Practicing criterion tasks from the outset may not be possible, and supplementing would require sophisticated instrumentation. Computer-mediated variations of English's and Lindahl's template-matching procedures are, however, altogether conceivable: A system for teaching golf swings, in which students' swings generated real-time visual representations that could be compared to visual representations of the swings of masters is easy to imagine, as are similar systems for teaching many kinesthetically mediated tasks whose maintaining stimuli are not discriminable by learners.

Supplementing and self-initiated behavior. Supplementing initiating stimuli is deceptively attractive as a means for teaching safety-related behavior and other behavior that is largely self-initiated. Turning on the safety of a tank's main gun before loading, for example, has extrinsic initiating stimuli. But the main impetus for performance is simply the intent to make the response. Because means may not be apparent for augmenting an intent or for attenuating N that competes with the intent, supplementing is likely to be chosen by default. A warning light may be placed on the main-gun safety switch, for example. That measure will not work. If supplements are used in training and withdrawn, the undesired behavior will reappear. Carrying the supplements over onto the job, as by redesigning equipment to incorporate the supplements, also will not work if we attach no

differential consequences to performing and not performing desired responses. And if we do attach differential consequences, then there is no need to supplement the initiating stimuli.

Clearly it is not the initiating stimuli that need to be operated on to strengthen self-initiated behavior, but the maintaining stimuli. Here again, supplementing may be chosen by default: Augmenting the explosions that might be caused by loading with the safety off makes little sense, as does attenuating N. The only alternative is to add a supplement. This is most effectively done, not in training, but by redesigning equipment to increase the salience of maintaining stimuli associated with an undesired response – designing guns so they cannot be loaded with the safety off. If practical constraints are such that the equipment cannot be redesigned and we decide to use supplements in training, then we should prepare to live with the consequences: The absence of the supplement <u>in situ</u> guarantees reappearance of the undesired behavior. That problem has no easy solution. If we can determine that the performance deficiency is attributable to lack of skill or knowledge, then refresher training, which uses and fades a supplement and which begins immediately after the first occurrence of the undesired behavior <u>in situ</u>, may work. Performance deficiencies in safety-related behavior are however usually attributable, not to deficiencies in skill or knowledge, but to deficiencies in motivation (Mager and Pipe, 1970). And the solution for motivational problems lies, not in adaptive or in any other kind of training, but in applying salient differential consequences on the job.

Summary of Hypotheses

Development of the notional adaptive training paradigm, examination of its underlying assumptions, and review of a few studies suggested several variables that can be expected to affect the effectiveness of salience-altering techniques. Before presenting algorithms for using adaptive methods, I shall review important variables and my thinking about their effects. The variables, underscored, and hypotheses about their effects are:

1. <u>Difficulty</u>: Salience-altering techniques will be more effective with difficult tasks than with easy tasks. This is so by definition: Evaluations of salience-altering methods require comparisons with the performance of control groups who practice unaltered criterion tasks. Extending that line of thought leads me to conclude that the effects of salience-altering techniques will be most dramatic with tasks that are impossible to learn by criterion practice alone. Special cases of the difficulty variable are (a) <u>mental ability</u>, (b) <u>stage of learning</u>, (c) <u>proficiency</u>, and (d) <u>amount of experience</u>; they affect task difficulty for a given individual and therefore affect the effectiveness of salience-altering techniques.

2. Initiating and maintaining stimuli: Salience-altering techniques will be most effective with tasks that are difficult to learn because the stimuli that initiate task performance, maintain task performance, or both are not salient. Tasks that are difficult to learn for reasons other than low salience of initiating stimuli or maintaining stimuli seem few; those whose essence of performance is speed may constitute exceptions.

3. Means of altering salience: All things being equal, augmenting S or attenuating N will be more effective than supplementing S. The use of supplements in practice invites response control by stimuli that are absent in the criterion task, with attendant undesired effects on transfer via the crutch effect. As for the choice between augmenting S or attenuating N, it may not matter for many tasks, because salience is increased in either event. For criterion tasks in which salience is low because of complex stimulus environments, however, attenuating N would seem to make more sense than augmenting S, although no research seems to support that view.

4. Sensory mode: I include this variable because, contrary to the implications in the previous paragraph, all things are not equal. Augmenting S and attenuating N are difficult to do for some tasks, notably those whose chief maintaining stimuli are kinesthetic. Those stimuli can be augmented by slow practice, but slow practice invites undesired transfer effects by altering criterion responses. Supplementing was successfully used by English (1942) and by Lindahl (1945) to teach motor skills whose maintaining stimuli were (a) kinesthetic, (b) indistinguishable by novices from irrelevant stimuli, and (c) not easily mastered by practicing the transfer task.

5. Fading: Predicting the effects of fading can be done by considering the conditions under which the crutch effect is and is not likely to occur. Important variables are (a) task difficulty, (b) means for increasing salience (augmenting, supplementing, attenuating), and (c) salience of initiating and maintaining stimuli in the practice and transfer tasks. Although I cannot predict the effects of all possible combinations of these variables, one conclusion seems clear: If a salient supplement is added to a salient criterion stimulus and abruptly withdrawn, the crutch effect will occur. The effects of supplementing or augmenting low-salience criterion stimuli are less clear. Goldiamond's (1965) work suggested that if low-salience criterion stimuli are augmented, the crutch effect is less likely to occur with fading than without. English (1941) and Lindahl (1945) supplemented low-salience maintaining stimuli without fading, however, and the results were favorable. It is important in considering such studies that we not focus only on the performance of the experimental groups, but consider the performance of control groups as well: If a task is so difficult that control groups never learn it, then despite the operation

of crutch effects or other detriments to performance, experimental groups will perform better than control groups.

6. <u>Salience of practice stimuli relative to salience of criterion stimuli</u>: Table 1 presents combinations of high- and low-salience stimuli in practice and criterion tasks. The capital letters correspond to

Table 1

Combinations of Practice and Criterion Stimuli (Letters correspond to hypotheses in text.)

Practice Stimuli	Criterion Stimuli	
Supplementing Signal	Low Salience	High Salience
Low Salience	A	F
High Salience	B	G
Augmenting Signal		
Low Salience	C	H
High Salience	D	I
Attenuating Noise	E	J

the lettering of the following hypotheses about interactions between practice and criterion stimuli:

A. Supplementing a low salience criterion stimulus with a low salience supplement will offer no advantage over supplementing with a high salience practice stimulus.

B. Supplementing a low salience criterion stimulus with a high salience practice stimulus will be effective. The supplement should be faded, to avoid crutch effects.

C. Low salience augmenting of a low salience criterion stimulus by increasing the value of one of its properties to a point where it is still low will be ineffective. Augmenting a low salience criterion stimulus should be done in a way that makes it a high salience criterion stimulus.

D. Augmenting by increasing a value of a property of the criterion stimulus to a point where the stimulus is salient will be effective. Fading should be used if the differences between criterion and augmented salience exceeds 1 j.n.d.

E. Attenuating N to make low salience criterion stimuli salient will be effective. Fading should be used if the difference between criterion and practice salience exceeds 1 j.n.d.

F,G,H,I,J. No benefits in increasing the salience of high salience criterion stimuli are apparent. Crutch effects are invited by the operations implied in cell G (high salience supplement added to high salience criterion stimuli) and in cell J (attenuating N in high salience criterion stimuli).

Algorithms

The considerations discussed thus far led to development of the algorithms in Figures 1, 2, 3, and 4. Figure 1 summarizes the procedure for determining whether a salience-altering method will be more efficient than practicing the criterion and, if so, whether to supplement, augment, or attenuate. Figures 2, 3, and 4 differ only in whether supplementing, augmenting, or attenuating is used to alter salience.

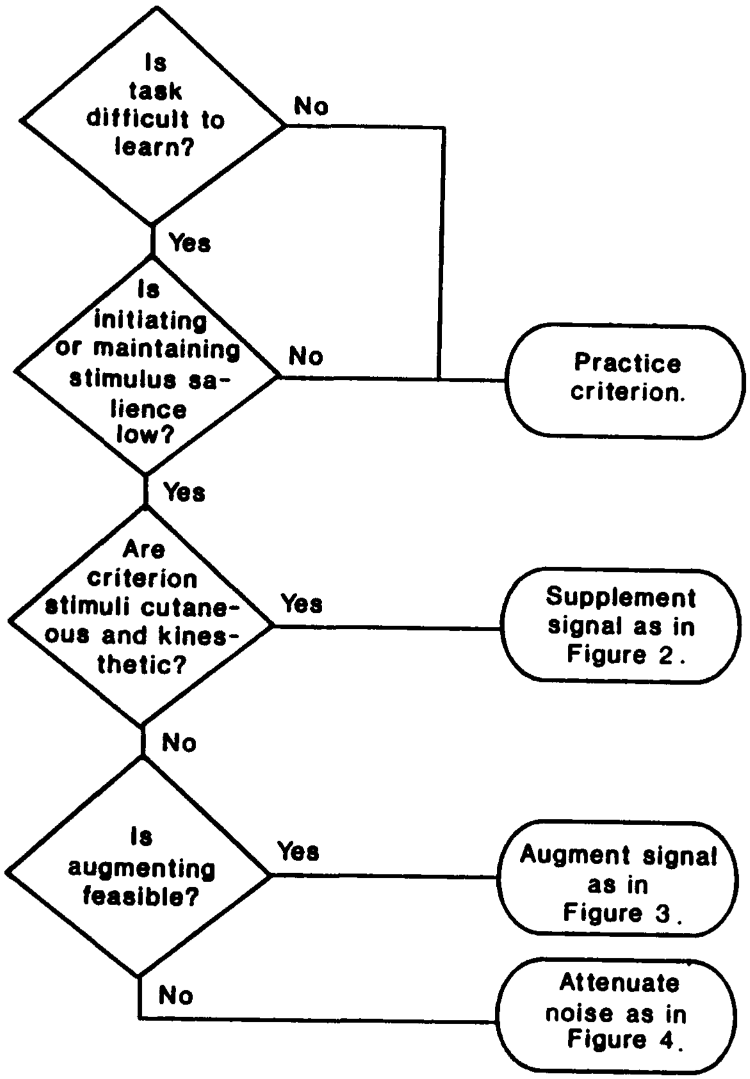

Figure 1. Algorithm for deciding whether and how to increase salience.

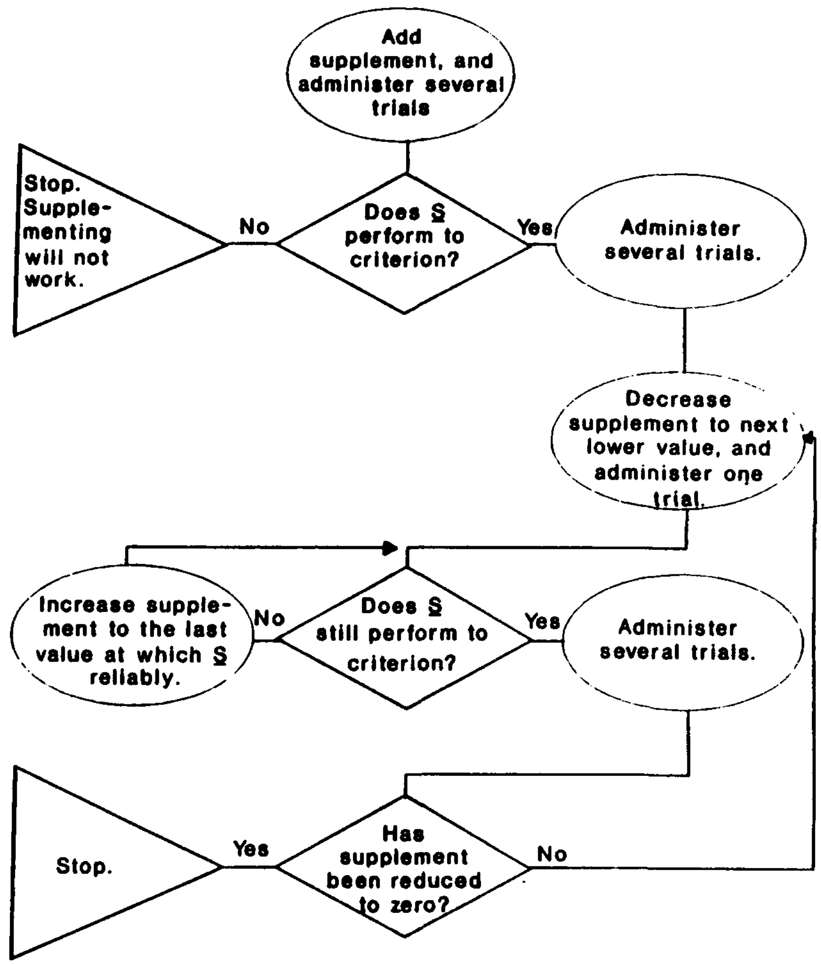

Figure 2. Algorithm for supplementing.

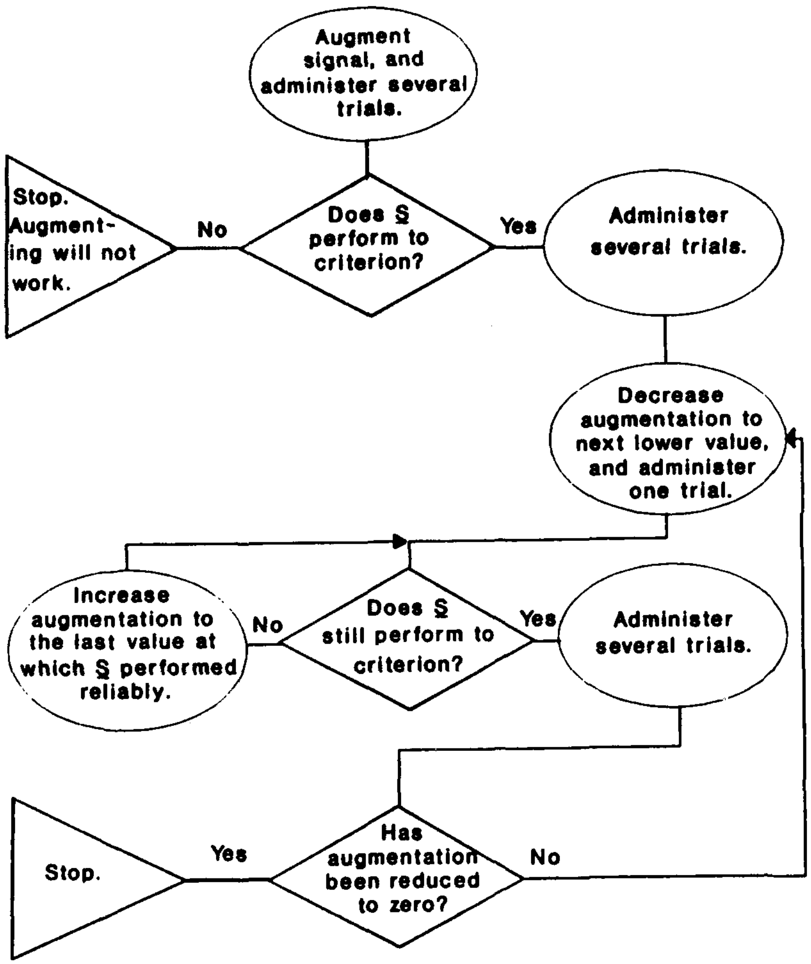

Figure 3. Algorithm for augmenting.

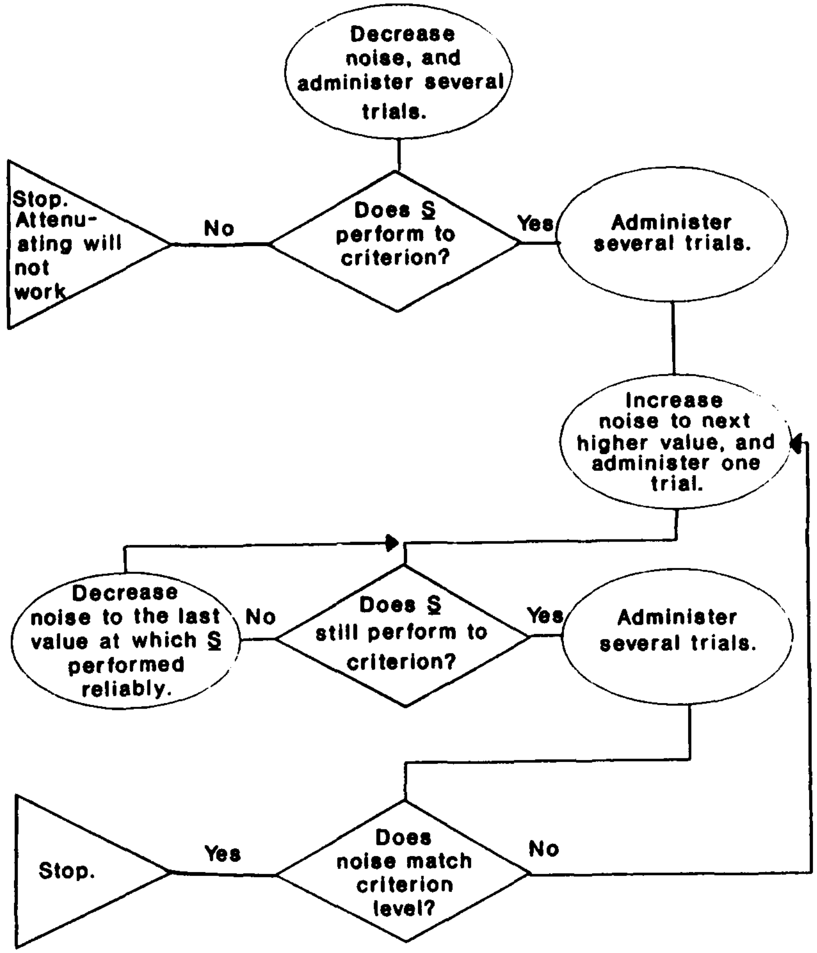

Figure 4. Algorithm for attenuating.

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